Wave-Coherence Measurements Using Synthetic Aperture Radar

David T. Walker
Earth Sciences Group, Veridian ERIM International
P.O. Box 134008, Ann Arbor, MI 48113-4008
phone: (734)994-1200 x2987 fax: (734)994-5824 email: dwalker@erim-int.com

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LONG-TERM GOAL

To develop methods to utilize synthetic-aperture radar (SAR) to characterize wave coherence on scales relevant to the design of mobile off-shore bases (MOB).

OBJECTIVES

There are two basic objectives to this program: (1) to develop the appropriate measures of wave coherence and methods of application for SAR image data, and (2) to apply the methods to available SAR data sets.

APPROACH

Methodology for determining the crest-length distribution using SAR image data, including error metrics, will be developed and then validated using available ground truth.

WORK COMPLETED

Methods for characterizing crest-length distributions have been developed and applied to both simulated and actual SAR data. The impact of SAR imaging effects on the results has been assessed and guidelines have been developed to mitigate that impact.

RESULTS

The distribution of wave-crest lengths on the ocean surface can be shown to primarily depend on the directional spread of the wave spectrum. It is well known, however, that SAR imaging effects can alter the apparent directional spread of the wave spectrum. How the SAR imaging effects manifest themselves depends on the wavelength of the waves, the significant wave height, and the SAR look direction relative to the wave propagation direction. To investigate the effects of SAR imaging on the apparent crest-length distribution derived from a SAR image, a series of forward predictions of the SAR image spectrum for known wave spectra were carried out using the Hasselmann formulation [1,2]. Simulations were made over a range of significant wave heights (2–10 m), dominant wave frequencies (0.06–0.09 Hz), and SAR look directions relative to the wave propagation direction. The SAR parameters for the simulations were those typical of satellite SAR sensors (specifically the European Space Agency's ERS platform).

Figure 1 shows the apparent directional spread of the SAR spectrum, divided by the directional spread of the actual wave spectrum, as a function of the SAR look direction relative to the dominant wave direction for three significant wave heights. These results are for a narrow wave spectrum ($\Delta\phi$=0.105 rad) and a dominant wavelength of 500 m. For all wave heights, the error increases with look direction and becomes constant at an apparent directional spread which is about 30–40% too low near a relative look angle of 20°. The apparent narrowing of the wave spectrum is due to the narrow azimuth pass band associated with the SAR imaging process, and the consequent distortion of the wave spectrum. The errors for this case are conservative in the sense that the apparent directional spread would indicate that the crests longer than they actually are. For shorter wavelengths, and larger directional spreading , the effects can be more pronounced.

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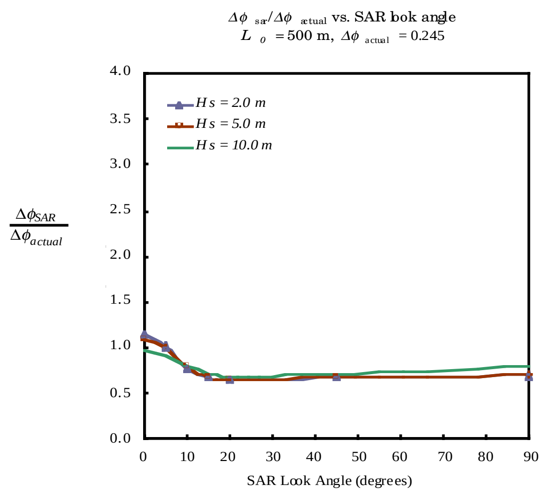

Figure 1: Apparent directional spread $\Delta\phi_{\text{SAR}}$ from simulated SAR image normalized with actual directional spread $\Delta\phi_{\text{Actual}} = 0.105$ for various SAR look directions relative to the dominant wave direction for $H_s = 2.0$ m, 5 m and 10.0 m for $\lambda = 500$ m.

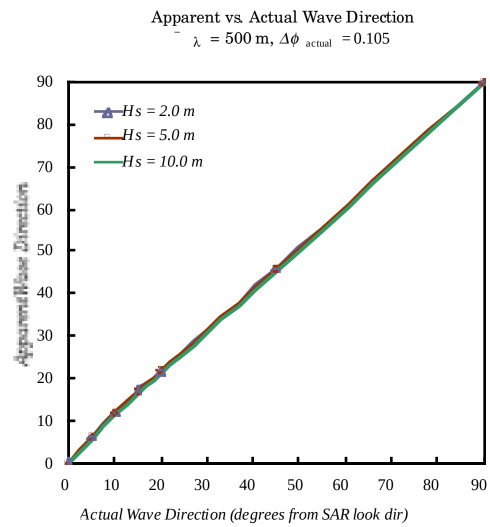

Figure 2: Apparent wave direction for $\Delta\phi_{\text{Actual}} = 0.105$ vs. actual wave direction with $H_s = 2.0$ m, 5 m and 10.0 m, and $\lambda = 500$ m.

From figure 1, it is clear that the amount of error in the directional spread determined from the SAR image spectrum depends on the look direction of the SAR relative to the wave direction. The apparent wave direction can be estimated from the location of the peak in the SAR spectrum. Figure 2 shows the apparent wave direction plotted versus SAR look direction for the spectra discussed in figure 1. From the figure, it is clear that the wave direction can be estimated within a few percent from the SAR spectrum under all conditions. Hence, the wave direction can be estimated accurately from the SAR spectrum.

Figure 3a shows and ERS SAR image collected on 24 December 1995 off the coast of Oregon, at approximately 44.5^{o} N and 124.5^{o} W. The significant wave height measured by a nearby NOAA/NDBC buoy was approximately 3.3 m, and the peak period was 16.7 sec. The crest recognition algorithm was run on this data, resulting in the crest map shown in figure 3b. The crest length distribution for this data, as shown in figure 3c, is characterized by the parameters L_o=1220 m and N_o=1 per km^2. This distribution implies that the number of wave crests with crest lengths greater than 2 km, the range of interest for MOB design, is approximately 0.2 per km^2. Based on simulation data such as that shown above, it is expected that these results are accurate to within about 10%.

REFERENCES

[1] Hasselmann, K. and S. Hasselmann, “On the nonlinear mapping of an ocean wave spectrum into a synthetic aperture radar image spectrum and its inversion,” *J. Geophys. Res.* **96**, 10 713–10 729, (1991).

[2] Krogstad, H.E., “A simple derivation of Hasselmann’s nonlinear ocean-to-synthetic aperture radar transform,” *J. Geophys. Res.* **97**, 2421–2425, (1992).

PUBLICATIONS

Walker, D.T., Lyzenga, D.R. & Renouf, M.A. Characterizing wave coherence with satellite-based synthetic aperture radar. *Proceedings of the Third International Workshop on Very Large Floating Structures (VLFS 99).* (ed. R.C. Ertekin & J.W. Kim). Vol I, 29–36, (1999).

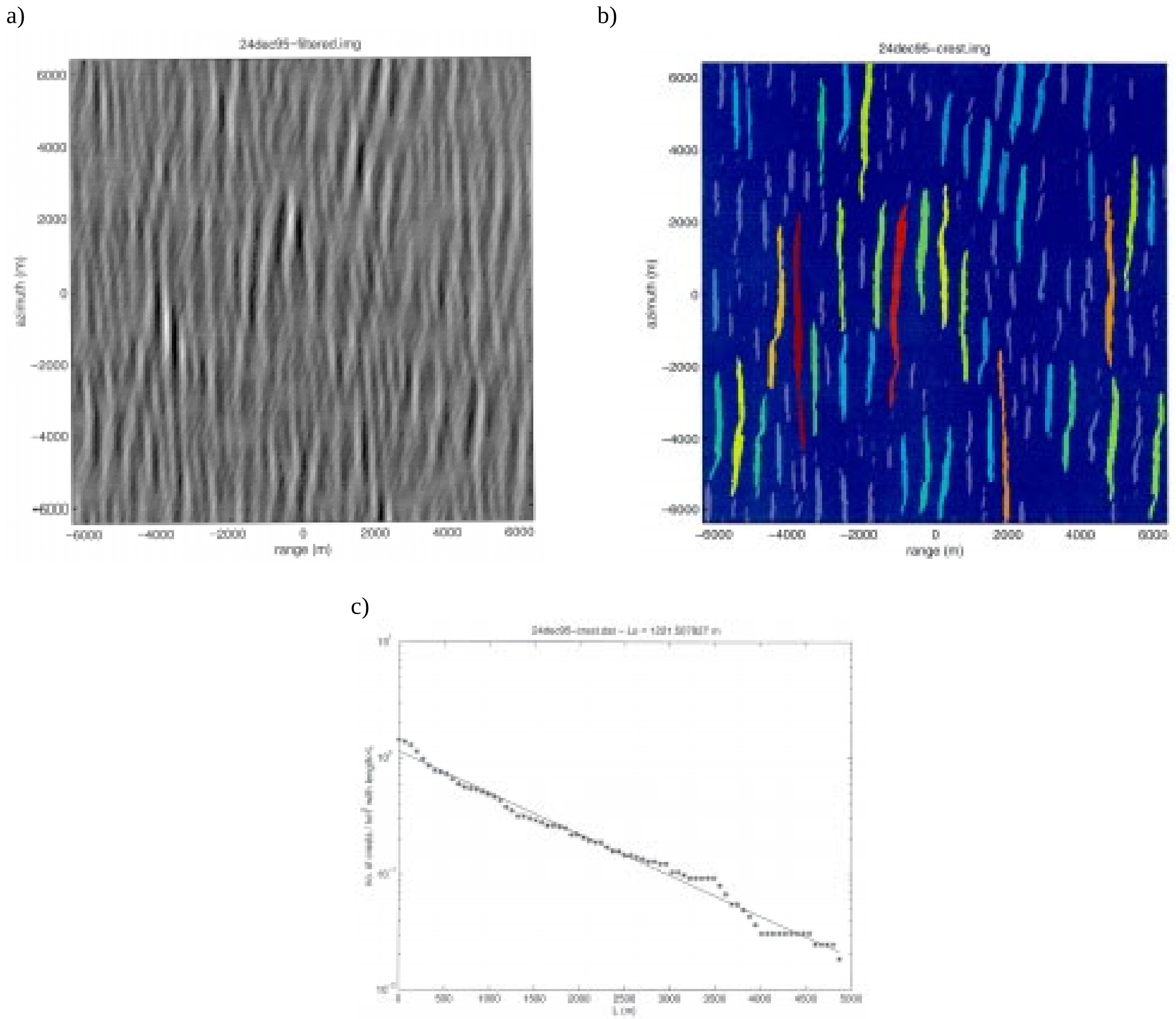

Figure 3: Results for a SAR image of waves off the Oregon coast; a) filtered SAR image, b) wave crests identified in SAR image, and c) crest length distribution.

IMPACT/APPLICATION

The development of approaches to use satellite-based SAR data to determine wave coherence for MOB design will allow the available archive of SAR data, which spans a number of years, to be used to obtain this information. This may eliminate the need for a costly field-measurement program to obtain this data.

TRANSITIONS

Results were presented at two MOB Technology Exchange Conferences and the 1999 Workshop on Very Large Floating Structures.

RELATED PROJECTS

This project is related to other efforts under the MOB Wave Coherence program. These other efforts focus on developing both improved measures and understanding of nonlinearity and wave coherence.